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Determinants of supplementary heating system choices and adoption consideration in Finland

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ABSTRACT

Detached house owners can improve energy efficiency in heating by adding a supplementary heating system alongside the primary mode. Whereas research on primary heating mode adoption is wide, studies focusing solely on the determinants of supplementary heating system adoption is limited. This study examines the determinants of supplementary heating system adoption and consideration in Finland with a survey data collected from a sample of newly built detached house owners. We employ discrete choice modeling to investigate the homeowners' supplementary heating system choices and interpret the results vis-à-vis the diffusion of innovations literature. The supplementary heating systems under study are solar panel, solar thermal heater, air-source heat pump and water-circulating fireplace. Overall, the findings indicate that homeowners are generally receptive to supplementary heating in Finland. The analyses show that several factors such as age, education, primary heating mode, heating system attributes, location, environmental attitudes and information channels impact the supplementary heating system adoption decision.

1. Introduction

One potential heating-related efficiency solution for households is to add a supplementary heating system (SHS) to complement their primary heating system. An SHS combined with a suitable primary heating system in a hybrid[1] solution can provide significant efficiency gains in heating and enable monetary savings for households [1,2].

This study examines the determinants of supplementary heating system adoption decisions in Finland. Finland is a country in the northernmost part of the EU belonging to Dfc in Köppen-Geiger climate classification, indicating subarctic climate conditions being dominant in nearly the entire country [3][2]. Thus in 2019, >82% of the Finnish within-household energy use was related to heating space and water, whereas cooling accounts for only a minor proportion of the energy usage [4].[3]

In Finland it is common to have a system capable of providing supplementary heating alongside the primary mode in a detached house. A traditional SHS is a regular fireplace or cooking oven. On the other hand, the number of households using other supplementary heating technologies has been increasing [5,6].

Four SHS options specifically acquired for supplementing space heating were identified during the study planning. These were air-source heat pump (ASHP), solar panel (SP)[4], solar thermal heater (STH), and water-circulating fireplace (WCF). Together these SHSs form the efficient supplementary heating system (*ESHS*) category. These alternatives provide an efficiency improvement for primary heating systems and traditional fireplaces[5]. WCFs offer an efficiency improvement over conventional fireplaces due to their heat-storing capability, i.e., the heat generated is transferred to a water boiler.

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[1] The definition of hybrid heating is not yet perfectly established. Usually, hybrid heating is thought to be a combination of two or more systems used for heat generation.

[2] Jylhä et al. [40] have observed a slight further penetration of Dfb type in the Southern Finland.

[3] Estimated heating degree days were 3793 and cooling degree days 190 with the 2012 weather in Helsinki-Vantaa [41]. Our survey focused on heating aspects and cooling is beyond the scope of the paper.

[4] We acknowledge that SPs are usually used for daily electricity consumption needs. However, in Finland, SPs are normally installed in homes with electric heating.

[5] Fireplaces and cooking ovens also have additional use purposes such as cooking and decoration.

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STHs and SPs provide emissions-free and costless solar energy when it is available. ASHPs provide considerable efficiency improvements, especially when combined with electric or oil heating.

Several factors may slow down the uptake of *ESHS*s. First, choosing a suitable SHS is a relatively complex task. Decisions on installing SHSs are made in very diverse contexts with respect to household energy consumption habits, local conditions, house characteristics, and primary heating system integration. Heterogeneity in homeowner preferences for technical characteristics such as comfort[6] of use further complicates the adoption processes. In addition, there is an opportunity cost on the time spent for information search on heating systems. The fact that SHSs are optional may decrease homeowners' willingness to even consider such an investment. Furthermore, energy-related choices may be characterized by several common deviations from rational decision-making such as default option inertia, satisfaction with the good-enough choice, the sunk cost fallacy, temporal discounts, and social comparisons as a driver of choices [7]. All the above-mentioned issues highlight the need to ease and clarify the SHS adoption processes.

Households' residential heating system choices have been studied extensively. For a literature review focusing on primary heating system decisions, see, for instance [8,9]. Studies that jointly examine primary and supplementary heating system (hybrid) choices include [10] for Greece, [11] and [1] for Finland, [12] for Germany, and [13] for the UK. Whereas research on primary heating mode adoption is wide and studies on hybrid heating exist, studies focusing solely on the determinants of SHS adoption decisions is somewhat limited. ASHP adoption has not been widely investigated from a complimentary system point of view for heating. Primary mode ASHP studies include [14] and [15]. Moreover, the literature lacks studies on the adoption of the WCF overall. On the other hand, the literature on the solar based supplementary heating and microgeneration is quite rich: studies and reviews include [16] for STHs, [17] for SPs, and [18] for both STHs and SPs.

This study contributes to the existing literature in several ways. First, it studies the adoption determinants of several SHS technologies. Literature includes studies focusing on a single technology (see, e.g., [15,17,19], but simultaneous account of multiple SHSs is missing[7]. Second, this study uses a household-level survey data including realized SHS adoption decisions and a rich set of explanatory variables on the possible adoption determinants (see Section 2.1), that is not common in the literature. Previous studies have often used adoption intention instead of actual adoption decision (e.g., [10,13,15]). Third, this study not only examines differences between adopters and nonadopters but also investigates adoption consideration.

We specifically designed a survey to study households hybrid heating choices in Finland to get the data to address these gaps. To examine adoption decisions, we use statistical analysis and discrete choice modeling. Generally, discrete choice models describe, explain and predict decision maker's decisions between two or more alternatives (see, [20] for further information). These models are widely utilized to study people's heating system decisions (see, e.g., [1,21,22]). Discrete choice analysis enables us to associate the SHS adoption choice to the characteristics and perceptions of the person and the attributes of the SHSs. The diffusion of innovations theory [23] provides us with the theoretical framework for discussion and interpretation.

[6] The perceived comfort of a heating system may differ in many ways, such as its response time, ease of adjustment, daily operation needs and maintenance.

[7] For electricity and energy microgeneration adoption studies see [42] for the UK and [43] for Greece.

2. Material and methods

2.1. Data

Section 2.1 describes the survey and the resulting data used in this study. Then, Section 2.2 continues by presenting the discrete choice models utilized in the data analysis.

The data of this study is based on a survey, which was developed to investigate households' primary and supplementary heating system choices. The survey began with an examination of existing heating system knowledge, information channels and environmental attitudes. Part two focused on the actual primary and supplementary heating system choices and house characteristics. Adoption consideration given to different primary heating systems and four *ESHS*s was recorded in part three. This was followed by heating system attribute and hybrid heating claims as well as a choice experiment focusing on hypothetical heating system choices. Finally, sociodemographic information was gathered.

The survey data has previously been used in Ruokamo [1] to study households' hypothetical hybrid heating system choices, and preliminary analysis of homeowners' primary heating system and *ESHS* choices was conducted in Räihä [24].

The survey data collection was a one-time event which occurred in August and September in 2014. The questionnaire was posted[8] to 2000 randomly selected Finnish homeowners who had built a new detached house between January 2012 and May 2014. The random sample covers roughly 8% of the entire detached house stock completed in Finland within that period. New detached house owners were selected as a target group because the survey intention was to focus on more recent heating system alternatives (see [1] for more information). In addition, targeting these individuals ensured quality answers because these homeowners had just recently made heating system choices and were assumed to be at least somewhat familiar with available primary and supplementary heating system alternatives.

A total of 432 survey responses were returned, resulting in a response rate of 21.6%. The collected sample is representative for the new detached house homeowners regarding age, gender, and household size (see also [1]). A slight underrepresentation of the country's northern regions is present due to the exclusion of the city of Oulu area. The data from Oulu were gathered with a separate survey and at a different stage of the building process, and thus, they are not included in the analysis.

Due to missing answers, the sample consists of 429 respondents. Unless we state otherwise, "do-not-know" answers and missing answers are excluded from the analyses across all formulations. Statistical and discrete choice analyses are conducted with NLOGIT 5.0 software.

Nearly all of the survey respondents (92.5%) had some type of SHS in addition to the primary heating system. Approximately 85% of the respondents had a regular fireplace, cooking oven or both. The *ESHS* variable consists of adopters (n = 74) who had installed at least one of the systems in their house. System count including double adoptions is 44 for ASHP, 20 for STH, 14 for WCF and 4 for SP.[9]

Next, we present the means and proportions of potential explanatory variables for the adoption regarding the whole sample, nonadopters (*No ESHS*) and adopters of *ESHS*. We employ the

[8] The survey was sent in August with couple of weeks to respond to the survey. It was addressed to the oldest owner of the house.

[9] At data collection in 2014, the four ESHS adoption rates were at the best cases in the early majority stage for ASHP and in the case of SPs, SPHs and WCFs in the very early stage. Since then, the installations of ASHPs along with other heat pump systems have sped up in Finland [5]. STH and SP adoption rates have also been increasing and are expected to continue to grow [44–46]. The ASHP is the most common *ESHS* in Finland [5,6] and is often utilized for space heating purposes.

framework introduced by Michelsen and Madlener [12] to guide the classification of potential explanatory variables. Sociodemographic, house-related and area-related variables are presented in Table 1.

The location of the respondent is known down to a postal code level. Utilizing this information, we create two geographical explanatory variables. The heating degree day impact is captured by the variable *HeatDgr*. It is the estimated heating need based on Finnish Meteorological Institute's S17 heating degree day information with the averages over years 1971–2000. Each observation is assigned the nearest available estimate with values ranging from 3911 to 6601.

Another seemingly relevant geographical factor is the division between coastal and noncoastal areas. The *NoCoast* variable reflects these differences. The *NoCoast* region is depicted with darker color in Fig. 1.

Knowledge of a product's existence is the first requirement for possible adoption. WCFs and STHs were the least familiar SHSs. Approximately 30% of respondents were unaware of the existence of these systems before the survey. On the other hand, nearly all respondents had heard of SPs and ASHPs, and only a few were not familiar with any of the investigated systems.

Respondents used, on average, four different channels to acquire information on residential heating systems and the total number of information channels used per person varies from 1 to 9. For the entire sample, the Internet (78%) and friends (77%) are the two most utilized information channels. These are followed by newspapers (*Newspap*, 58%), housing exhibitions (*Exhibit*, 55%), experts and professionals (*Experts*, 52%), professional literature (*Literat*, 39%), television (*TV*, 36%), and building supervision (*Supervis*, 10%). The survey also gathered data on the use of online heating system calculators, *Calculat*, and participation to heating system educational events, *HeatEdu*. Nearly half of the respondents were familiar with the existing calculators, and around 20% had participated to educational events.

Fig. 2 presents the information channels systems for non-adopters and adopters of *ESHS* separately. Largest differences between the two groups can be found in *Experts, Calculat, Friends* and *Literat*.

Table 2 lists variables about the information channels' impact on heating system adoption, with the sample limited to individuals who said they received information from the information channel in question. The self-evaluated impact on heating system decision was higher for experts and friends compared to calculators and educational events.

Environmental and efficiency-related variables are presented in Table 3. There is a strong agreement on the use of solar energy being too low (*MoreSolar*). The same applies for the need for energy savings even if it implies extra costs for society and the need to add renewables to the energy mix in general (*MoreRenew*). The question about the need for an environmentally superior alternative to oil or direct electric heating (see variable *NoOil*) may reflect different beliefs about future electricity generation; there is now more talk of electrification of the heating system as electricity generation in Finland becomes cleaner.

Some of the respondents are willing to decrease the ambient home temperature (*Ambient*). This may reflect not only respondents' but also other household members' comfort requirements. The house-specific energy efficiency certificate (*Elabel*), of which calculation the heating system plays an essential part, is stated to have a relatively minor role in heating system selection. Finally, approximately 14% of respondents do not know if district heating is an ecological alternative. This is very understandable in the prevailing situation because district heating plants utilize many kinds of fuel sources, such as coal, peat and wood.

The share of ground source heat pumps in new buildings is quite high in Finland, with 48% of the sample having *GrndHeat* as their primary heating mode. The other primary heating system shares are 18% for electric storage or direct electric heating (*Electric*), 16% for exhaust-air or air-to-water heat pump (*HeatPump*), 12% for district heating or other RHS (*DHetc*) and 7% for wood boiler (*Wood*).

Fig. 3 presents the primary heating system choices of the adopters and nonadopters of *ESHS* separately. The largest differences are in *GrndHeat* and *Electric* shares. Among non-adopters, *GrndHeat* is the most popular primary heating mode with 56% share whereas with *ESHS* adopters it is *Electric* with 39%. Looking it from the other way around, only 5% of ground heat system owners have an *ESHS*. The corresponding rates for the other systems are 22% for *HeatPump*, 26% for *DHetc*, 24% for *Wood*, and 38% for *Electric*.

The questionnaire formulation specifically stressed that the *ESHS* alternatives are primarily to complement household space heating. The *ESHS*s cannot function as a sole heating source in Finland's cold climate conditions; this makes ASHP unlike air-to-water heat pumps and exhaust air heat pumps which in our case form the primary heating system category *HeatPump*.

The remaining variables include the importance of the investment cost (*InvCostM*), operating cost (*OpeCostM*), and comfort of use (*ComfortM*) scaled from not at all important (1) to very important (4).

In addition to homeowners' real primary and supplementary heating system choices, respondents indicated their level of consideration for each investigated *ESHS*. This data enables us to examine whether *ESHS* adopters view the other systems differently from nonadopters. The variable *Consider* includes individuals (n = 301) who had considered but had not acquired the specific *ESHS*. The *Rejector* variable indicates those individuals (n = 42) who did not consider the adoption of *ESHS*s at all or who indicated only a very low level of consideration.

The survey also included several claims related to hybrid heating systems that the respondents were expected to evaluate.

2.2. Discrete choice analysis

We apply discrete choice analysis [20,25] to study the determinants of the supplementary heating system choice. Discrete choice analysis allows to associate the *ESHS* adoption choice to various individual characteristics and perceptions as well as technology characteristics of heating systems. The homeowners' actual *ESHS* choices are analyzed with a binomial logit (BL) model. We also utilize the data on homeowners' consideration of other nonadopted *ESHS* in a multinomial logit (MNL) model framework and examine how the level of consideration is reflected in the taste variation.

The BL and MNL models are derived from the random utility framework [26]. Here, the utility U_{ij} for individual i relating to each alternative j is written as

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \beta_j x_i + \varepsilon_{ij}, \tag{1}$$

where V_{ij} is the deterministic component and ε_{ij} is the unobservable error term. The deterministic component is further described by explanatory variables x_i and corresponding parameters β_j. The error term ε_{ij} is assumed to be independently and identically distributed with an extreme value type 1 distribution. With these assumptions, the conditional choice probability for logit is

$$P_{ij} = expV_{ij} / \sum_{k=1}^{j} expV_{ik}. \tag{2}$$

The magnitudes of the logit model coefficients are slightly difficult to interpret. Therefore, we examine the marginal effects to draw conclusions on the changes. These effects can be calculated via

Table 1
Sociodemographic, house-related and location-related variables.

Variable	Definition	Sample (n = 429)	*No ESHS* (n = 355)	*ESHS* (n = 74)
Income	Monthly gross income of household (5 categories with 2 K bins within <2000€–>8000€)	3.47 (1.04)	3.51 (1.03)	3.28 (1.08)
Age	Age of the respondent (metric)	42.41 (12.0)	42.6 (11.94)	41.5 (12.37)
FamMbrs	Number of household members (metric)	3.27 (1.37)	3.28 (1.36)	3.25 (1.42)
Female	Respondent identifies as female (1 if yes)	0.26	0.27	0.22
HighEdu	Polytechnic or university-educated (1 if yes)	0.55	0.56	0.49
Profield	Technical or construction industry professional (1 if yes)	0.47	0.46	0.55
OwnWood	Access to firewood from family sources (1 if yes)	0.29	0.28	0.31
DHnet	House located in district heating network area (1 if yes)	0.21	0.22	0.18
Homesize	Heated floor space (5 categories: <100 m^2, category mean of 125 m^2, 175 m^2 and 225 m^2 and >250 m^2)	2.71 (0.94)	2.74 (0.95)	2.60 (0.92)
Lvinarea	Residence area (5 categories: rural area, small village, town, small city or big city)	3.00 (1.57)	2.93 (1.57)	3.30 (1.52)
HeatDgr	Annual S17 heating degree days of the nearest estimate based on FMI 1971–2000 averages	4703 (467)	4717 (475)	4636 (422)
NoCoast	House not near coastal regions (1 if yes)	0.27	0.26	0.30

[a] In brackets: Standard deviation.

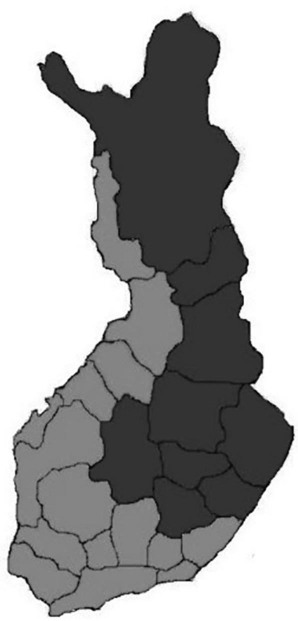

Fig. 1. The division between coastal and noncoastal areas. *NoCoast* encompasses Finnish postal code areas 40000–44999 50000–52999, 57000–59999, 70000–83999 87000–89999, 93000–93999 and >96000.

$$\partial P_{ij}/\partial x_i = P_{ij}[\beta_j - \sum\nolimits_k P_{ik}\beta_k] = P_{ij}(\beta_j - \overline{\beta}) \quad (3)$$

where the marginal effect depends on parameter estimate β_j and choice probability P_{ij}.

3. Results and discussion

3.1. Efficient supplementary heating system choice determinants

This section begins with the BL model analysis to study the *ESHS* choice determinants (Section 3.1). Then in Section 3.2, the analysis is expanded to the adoption consideration where statistical comparisons and the MNL model analysis are conducted. Finally, homeowners' general perceptions of hybrid heating systems are further investigated in Section 3.3.

The results of the BL model are reported in Table 4. After removing observations with missing answers, we have 395 respondents in the reported model. The results are robust to imputing missing values and "do-not-know" answers.

The model fit is relatively good, with the McFadden pseudo r^2 being 0.29.

Rogers (p.288) [23] states that early adopters are often younger and more highly educated. BL model results show that a one-year increase in *Age* decreases the probability of adopting an *ESHS* by 0.5%. This finding is similar with Willis et al. [27] for microgeneration technologies. University graduates, on the other hand, are somewhat less likely to adopt *ESHS* (*Univer*: -0.066^*) in this study.

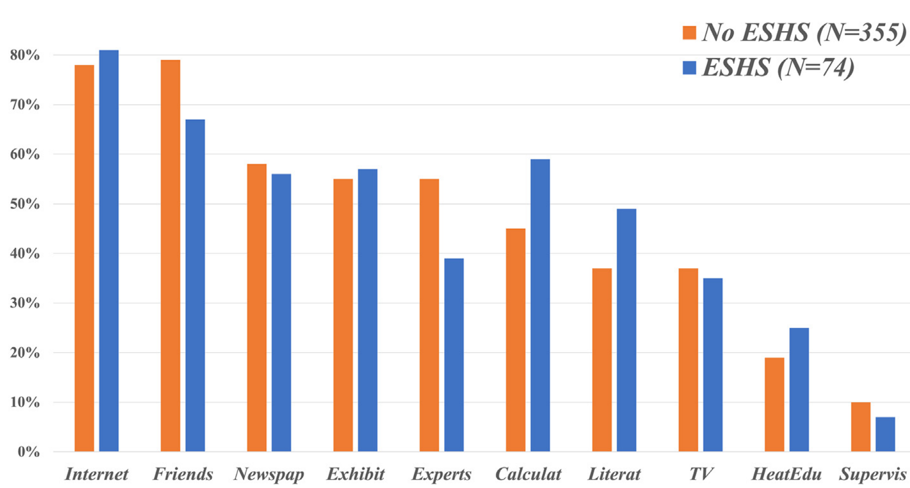

Fig. 2. Information channels used to get heating system knowledge.

Table 2
Information channels self-evaluated impact on decision.

Variable	Definition	Sample (n = 429)	*No ESHS* (n = 355)	*ESHS* (n = 74)
FriendImp	Friends impacted decision 1–5 (>0&|*friends* = 1)	3.41 (1.05)	3.44 (1.06)	3.23 (1.01)
ExpertImp	Experts impacted decision 1–5 (>0&|experts = 1)	3.78 (0.93)	3.81 (0.93)	3.59 (0.95)
HeatEduImp	*HeatEdu* decision impact 1–5 (>0&|*HeatEdu* = 1)	3.05 (1.14)	3.12 (1.14)	2.76 (1.14)
CalculatImp	*Calculat* decision impact1–5 (>0&|*Calculat* = 1)	3.06 (0.97)	3.15 (0.95)	2.70 (0.98)

[a] In brackets: Standard deviation.

Table 3
Environment- and energy-related variables.

Variable	Definition	Sample (n = 429)	*No ESHS* (n = 355)	*ESHS* (n = 74)
EnvironM	How important environmental friendliness is for your residential heating system (RHS) choices (1–4)	3.15 (0.67)	3.14 (0.69)	3.21 (0.58)
MoreRenew	More renewables use is needed, even if it implies additional costs to society (1–5)	4.05 (0.89)	4.03 (0.91)	4.14 (0.83)
EnergySave	How important energy saving is in mitigating climate change (1–5)	4.13 (0.94)	4.12 (0.93)	4.17 (1.03)
ExtraEco	Willing to pay extra for an ecological heating system (1–5)	2.97 (1.25)	3.00 (1.24)	2.85 (1.29)
DistEco	District heating is an ecological alternative (1–5)	3.37 (1.16)	3.39 (1.17)	3.26 (1.13)
Ambient	Willingness to lower the ambient home temperature (1–5)	3.65 (1.27)	3.64 (1.27)	3.70 (1.27)
MoreSolar	Solar energy use in space & water heating is currently too low (1–5)	4.39 (0.81)	4.36 (0.81)	4.49 (0.83)
Elabel	E-label impacts my RHS choices (1–5)	2.88 (1.25)	2.87 (1.25)	2.93 (1.28)
NoOil	RHS should be more ecological than direct electric or oil heating (1–5)	4.12 (1.03)	4.16(1.03)	3.93 (1.02)

[a] In brackets: Standard deviation.

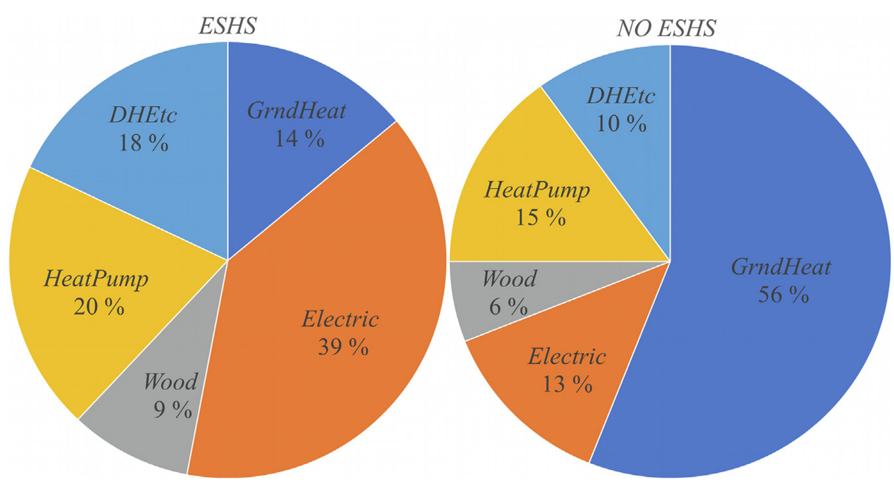

Fig. 3. Primary heating shares of *ESHS* adopters and non-adopters.

The results indicate that *Income* does not play a significant role in the *ESHS* adoption decision. *Homesize* on the other hand increases the likelihood to adopt. This is understandable since the relative advantage of an *ESHS* increases the larger the heated floor area is.

Information channels are closely related to the diffusion of innovations. All information channels are not alike, and sometimes there can even be information overload [7,23]. Mahapatra and Gustafsson [28] discovered that interpersonal sources influence the diffusion of residential heating choices through persuasion, particularly for later adopters in Sweden. The results of this study indicate that discussions with friends decrease the adoption probability of *ESHS* by 13%, ceteris paribus. In relatively early stages of technology diffusion, it is more likely that discussions are with other non-adopters, which may nudge toward more established solutions.[10] On the other hand, opinion leaders, impartiality or even general curiosity are identified to ease the adoption in the diffusion of innovations framework. Professional literature is one such way to seek detailed information. We find that the use of *Literat* as an information source increases the adoption likelihood by 8.6%.

Living in the district heating network area, *DHnet*[11] decreases the probability of adopting *ESHS*s. If the house is located in the district heating network area, district heating is often the primary heating mode choice, and the benefits from adding an *ESHS* are weaker due to difficulty in quickly adjusting incoming district heat and the high monthly fixed costs of using district heat.

According to the results, having *GrndHeat* as the primary heating mode decreases the *ESHS* adoption probability strongly (by 26%). Ground heating has been sold as a standalone solution in Finland so it is not surprising that the most expensive and energy-efficient ground source heat pump is far less likely to be coupled with an *ESHS* than other heat pump technologies and electric heating. However, ground source heat pump runs with electricity and can benefit from solar power [10]. Furthermore, Carbonell et al. [29] found significant energy savings when STHs and ground

[10] We lack detailed information about the type of RHS information that the household has received from different sources.

[11] For *DHnet*, we assume that a "do-not-know" answer also means "no".

Table 4
BL model for *ESHS* choice, average partial effects.

Variable	Marginal effect	Standard error
Age	−0.00497***	0.00163
Univer	−0.06615*	0.03964
Income	−0.00548	0.01699
Homesize	0.03924**	0.01942
Friends	−0.12762**	0.04955
Literat	0.08618**	0.03595
DHnet	−0.097643***	0.03565
GrndHeat	−0.26082***	0.03959
*Electric*OpeCImp interaction*	0.15576*	0.08963
Electric	0.02986	0.06164
Lvinarea	0.03308***	0.01209
HeatDgr	−0.00047***	0.00023
NoCoast	0.08572*	0.04570
InvCIMP	−0.10842***	0.03313
MoreRenew	0.05531***	0.01926
Model fit		
Observations (n)		395
Parameters (k)		15
McFadden pseudo r^2		0.29
Correct p at 0.5		80%
Log-likelihood		−126
Restricted log-likelihood		−178

[a] ***, **, * = statistical significance at 1%, 5% and 10% level, respectively.

heating were combined in southern Finland. Nevertheless, we observe STH adoption rate (7% vs. 2%), SP adoption rate (1.5% vs. 0.5%), and adoption consideration rates (2.61 vs. 2.47 for STH and 2.50 vs. 2.37 for SP) all consistently lower for *GrndHeat* compared to other primary heating modes. Interaction tests suggest the information channels driving these impacts are *Friends* and *Experts*. Part of the low *ESHS* adoption rate among ground source heat pump owners can be explained by the fact that the gains from combining ASHPs and ground heating are mostly only realized through quicker system control. It is also possible that the high investment cost of ground source heat pumps slows down *ESHS* investments.

We discover a positive relationship between pro-environmental values and *ESHS* choices, as indicated by *MoreRenew*. The probability of adoption increases by 5.5% with each category shift. This indicates that environmental values are linked with the *ESHS* adoption.

The negative sign on the *InvCIMP* variable (1 if *InvcostM* = 4) indicates that respondents who find investment costs very important are less likely to adopt *ESHS*s. Having direct electric or electric storage heating implies a larger potential for operating cost savings. Respondents who state that operating costs are very important (*OpeCostM* = 4) and also have electric heating are 14% more likely to acquire *ESHS*.[12] In general, costs and payback periods for *ESHS* technologies have continued to decrease. However, even economically sensible energy efficiency investments are often not undertaken [30]. Lack of awareness of the economic benefits or even expectations of further price drops can slow down adoption.

It has been shown that heating consumption is highly elastic to heating degree days [31], and the heating degree day has also been used in previous studies as an explanatory variable [32].We find that an increase of 1000 in the heating degree day value lowers the adoption probability by over 4.5%. The negative *HeatDgr* impact may be explained by less solar power potential in the north of Finland and the decreasing effectiveness of air-source heat pumps the colder the weather is. On the other hand, higher overall heating need should counteract this.

The increased probability of adopting *ESHS* in the *NoCoast* region is an expected result. In general, Finnish coastal regions are more densely populated and affluent. In addition to grid-related issues such as reliability, future investment needs and less stringent permit policies, relatively cheaper installation and building costs overall may leave more room for additional investments. Solar power potential, on the other hand, is somewhat larger on the coastline due to less cloud cover.

Finally, the *Lvinarea* variable shows that households living in more urban areas are more likely to adopt *ESHS*s. Storage space for wood is scarcer in densely populated areas. Additionally, small-particle emissions may make traditional wood-based SHSs less socially accepted in cities, raising the relative advantages of *ESHS*s. This would align with insight from the theory of planned behavior by Ajzen [33], with social norms and pressures mitigating the barriers to adoption. Taken together, the location variables suggest careful geographical targeting, and consideration of local conditions, regulations, peer effect and costs.

3.2. Adoption consideration

Table 5 shows how strongly adopters or nonadopters have considered each *ESHS* on a 1–4 scale (from 1="certainly not" to 4="certainly yes"). We compare the level of consideration through an examination of means. Here, for *ESHS*, we only include the non-adopted systems to avoid endogeneity.

The first column presents the levels of consideration of those who have adopted exactly one *ESHS*. The statistical significance of the mean difference is reported in the last column. The test is conducted with the nonparametric Mann-Whitney *U* test [34]. With a significance below the 1% level, *ESHS* adopters of other systems give more consideration to STC, SP and WCF systems. No statistical significance below the 5% level is detected for the level of the consideration given to ASHP systems. The second column includes those who have adopted multiple *ESHS*s. Again, *ESHS* adopters view other systems more positively than nonadopters. Generally, solar-based SHSs receive higher consideration scores.

Nonadopters form an interesting group. By dividing this group into *Rejectors* and *Considerers*, we may understand the actual adoption decision more thoroughly. Such information can be important for advertising and policy design. Hence, we execute the MNL model analysis. The results of the MNL model are presented in Table 6. The MNL model has a reasonable overall fit (0.30) measured with the McFadden pseudo r^2. The MNL model results align with the BL model results. In the following we discuss the main additional insights from the MNL model.

The variable *Female* does not have significant impact on *ESHS* choices or adoption consideration in our study. Previous research on the impact of the gender of the household head is inconclusive; men may be more likely to adopt technological innovations, and women are more positive towards pro-environmental innovations [18].

Ambient temperature can be the most important comfort aspect for households [35], but comfort has many layers. Comfort is not only about thermal aspects but also comfort of use and maintenance. Existing literature is divided about the impacts of comfort on primary heating system choices [1,28], and literature on SHS choices and comfort is limited. In this study, individuals stating high importance for heating system ease of use and maintenance (*ComfortM)* are slightly more likely to adopt *ESHS*s.

The results of the BL model imply that high education has no positive effect on *ESHS* adoption. However, the MNL model results indicate that high education actually increases the likelihood of being an *ESHS* adoption *Considerer* and decreases the likelihood of being a *Rejector*. For *GrndHeat* we observe that the probability of being a *Considerer* is more elevated than *Rejector* likelihood.

[12] In unreported formulations, interacting the *OpeCostM* variable with other primary heating modes seems to play a negligible role, and other factors drive the adoption.

Table 5
Level of consideration of efficient supplementary heating system adoption.

	One *ESHS* (n = 60)	*ESHS* (n = 65)	*No ESHS* (n = 332)	*U* test
ASHP	2.36 (1.08, 22)	2.40 (1.12, 25)	2.60 (0.96)	
STH	2.87 (0.95, 47)	2.88 (0.94, 48)	2.51 (1.00)	***
SP	2.83 (0.86, 58)	2.84 (0.81, 62)	2.42 (0.97)	***
WCF	2.34 (1.11, 53)	2.34 (1.1082, 53)	1.98 (0.97)	***

[a] In brackets: Standard deviation, number of observations.
[b] *** = two-tailed statistical significance at 1% level.

Table 6
Marginal effect results based on the MNL model estimates.

Variable	*ESHS*		*Consider*		*Rejector*	
	ME	SE	ME	SE	ME	SE
Age	−0.00550***	0.00176	0.00277	0.00224	0.00274*	0.00153
Income	−0.02837*	0.01857	0.01876	0.02513	0.00961	0.01857
Female	−0.00228	0.04196	0.02738	0.05439	−0.02511	0.03807
HighEdu	−0.06992*	0.03705	0.15123***	0.04977	−0.08131**	0.03595
Kids	0.02750	0.03892	−0.00724	0.05432	−0.01981	0.04145
Profield	0.01691	0.03634	0.01114	0.04779	−0.02805	0.03385
OwnWood	0.04459	0.03955	−0.01873	0.05029	−0.02586	0.03428
Homesize	0.01982	0.02149	0.01023	0.02814	−0.03005	0.02018
DHnet	−0.09872***	0.03874	0.09748*	0.05461	0.00125	0.04098
GrndHeat	−0.28166***	0.04627	0.20390***	0.05932	0.07777*	0.04146
Electric	0.012471**	0.05220	−0.03484	0.06030	−0.08993***	0.03288
Lvinarea	0.02612**	0.01246	−0.03710**	0.01657	0.01097	0.01202
NoCoast	0.13851**	0.05925	−0.07278	0.06697	−0.06573	0.03569
HeatDgr	−0.00015***	0.00006	0.00006	0.00006	0.00009**	0.00004
Supervis	−0.08227*	0.04870	0.06635	0.07303	0.01592	0.05814
Literat	0.08834**	0.03957	−0.08696*	0.04854	−0.00138	0.03232
Exhibit	0.03688	0.03462	0.02679	0.04622	−0.06367*	0.03357
Experts	−0.04612	0.03462	0.02691	0.04567	0.01921	0.03289
Calculat	0.07359**	0.03598	−0.07307*	0.04721	−0.00052	0.03376
Friends	−0.01387***	0.04871	0.13746**	0.05884	−0.00359	0.03873
InvCostM	−0.08761***	0.02565	0.06812*	0.03273	0.01949	0.02260
OpeCostM	0.03223	0.04001	−0.02476	0.05049	−0.00747	0.03391
ComfortM	0.05699*	0.03392	−0.04460	0.04422	−0.01239	0.03094
RHSeasy	−0.02458*	0.01280	−0.00992	0.01832	0.03450**	0.01431
PosElabl	0.04790	0.03771	0.02013	0.04659	−0.06803**	0.03014
MoreRenew	0.02762*	0.02086	−0.00767	0.02530	−0.01995	0.01640
Model fit						
Observations (n)			378			
Parameters (k)			54			
McFadden pseudo r^2			0.30			
Akaike information criteria			520			
Log-likelihood			−206			
Restricted log-likelihood			−293			

[a] ME: Average marginal effects.
[b] SE: Standard errors, calculated via the delta method.
[c] ***, **, * = statistical significance at 1%, 5% and 10% level, respectively.

If we assume *Rejector*s to be what the literature terms "laggards" (see, [23]), the group aligns fairly well with the demographic features of that category such as older age and lower education. They also do attend exhibitions to a somewhat lesser extent (*Exhibit*: −0.06367*). Investment cost importance also increases the probability of being a *Rejector*.

Respondents familiar with heating system calculators are more likely to adopt and less likely to be considerers. These results suggest that highlighting *ESHS* cost of use savings through accessible and context-personable information channels can impact adoption.

While we noted earlier that building energy label played a small role in adoption decisions, there is heterogeneity among the responses with fairly large standard deviation. If the respondent signaled that energy labels impact RHS decision (*PosElabl = Elabel >=4*), probability of being a rejector is lower. Also agreeing that heating system decisions are easy (*RHSeasy*) is associated with an increased likelihood of being a *Rejector*. These individuals may make more heuristic heating system decisions.

3.3. Hybrid heating views of adopters and nonadopters

The diffusion of innovations framework stresses the importance of early adopters for future adoption [23]. As Michelsen and Madlener [36] state, early adopters' positive word-of-mouth communication is also crucial for uptake of low carbon technologies. Consumer satisfaction with low carbon heating technologies was also studied by Bjørnstad [37]. Other important factors cover perceived and actual system characteristics as observed by nonadopters. In Table 7, we examine whether the views on hybrid heating of *ESHS* adopters differ from those of nonadopters. This gives us important and less-studied user insights into heating systems with hybrid characteristics and their future adoption prospects.

Table 7
Views of hybrid heating systems on a 1–5 scale.

"Hybrid heating systems…"	*ESHS*	*No ESHS*	*(Rejector)*
Are suitable for heating detached houses	4.54 (0.72, 8%)	4.30 (0.76, 14%)	4.03 (0.71, 17%)
Do not have enough relevant information available	3.94 (1.02, 14%)	3.77 (1.03, 14%)	3.74 (1.04, 17%)
Can reduce annual heating costs	4.55 (0.71, 14%)	4.42 (0.69, 16%)	4.25 (0.55, 14%)
Have excessively high investment costs	3.24 (1.20, 20%)	3.67 (1.05, 24%)	3.97 (0.97, 24%)
Increase the resale value of a detached house	3.97 (0.98, 18%)	3.87 (0.95, 21%)	3.59 (1.02, 19%)
Enable the lowering of the carbon footprint from heating	4.21 (0.95, 24%)	4.11 (0.78, 23%)	4.03 (0.66, 14%)
Present high levels of operational reliability	3.67 (1.14, 22%)	3.57 (0.85, 31%)	3.33 (0.92, 36%)
Should not be used without automated control system	3.33 (1.24, 31%)	3.58 (1.11, 41%)	3.55 (0.96, 48%)
Require higher-than-average know-how to use	3.39 (1.09, 16%)	3.76 (1.00, 23%)	3.91 (0.96, 24%)
Require more intensive maintenance, add extra work	2.80 (1.02, 19%)	2.96 (1.00, 32%)	3.15 (0.97, 38%)
Are adjustable	3.82 (0.81, 23%)	3.77 (0.85, 39%)	3.60 (0.60, 52%)
How good is your hybrid heating knowledge?	3.47 (1.14)	2.75 (1.18)	2.43 (0.95)

[a] In brackets are the standard deviations and percentage of "do-not-know" answers.
[b] "Do-not know" and missing answers are not included in mean & s.d calculus.

Hybrid solutions are widely considered suitable for household space heating purposes (compatibility). Respondents are also aware that hybrid solutions provide operating cost savings (relative advantage). The possibility of lowering a household's carbon footprint with hybrid heating is also generally accepted. The most critical obstacles appear to be information related from the point of view of both availability and knowledge. These can be compared with Claudelin et al. [38], who identified the lack of knowledge on potential costs savings, implementation costs and technology as key barriers to renewable energy technology adoption in Finland. The earlier observation on the investment cost being a barrier to some of the *Considerers* is also reflected here.

The notable standard deviation related to the reliable operation statement can reflect personal experiences among *ESHS* adopters. When asked, adopters are indeed somewhat more likely to have found areas for improvement in their existing heating systems (33% vs. 20%). This issue is connected to the trialability attribute of innovation diffusion and can influence adoption. For example, research suggests that operational reliability has hindered the continued momentum of the diffusion of pellet heating systems in the Nordics [39]. Closer investigation of the open-ended questions in this section reveals that areas for improvement were rarely found for SHSs and could in part reflect a higher level of awareness of the system function. Compared with the share of nonadopters, a larger percentage of *ESHS* adopters also answer that they are considering adding more SHSs (26% vs. 19%).

The most significant heterogeneity in within-group answers is observed in the items related to the need for automation, investment cost importance, expertise and maintenance needs, and resale value.

We also cover the views of *Rejector*s. There are quite significant differences between *Rejectors* and *ESHS* adopters across the claims. Moreover, a higher proportion of "do-not-know" responses among *Rejectors* suggests that these individuals require more information on hybrid heating. Since they also view heating system decisions easier, this group presents a challenge to adoption and would require a different approach.

Another way to examine the impact of knowledge on the perceptions of hybrid heating is to use the last question in Table 7, the self-reported hybrid heating knowledge, to classify the results. The mean scores attained through that formulation nearly uniformly imply that the more respondents say they know, the more positive their views are on hybrid heating systems.

4. Conclusion

This study investigates SHS choice, adoption consideration and hybrid heating attitudes among 432 Finnish homeowners who had recently made heating system decisions for their new house. The novel analysis combines realized adoption decisions of multiple *ESHS* options; STH, SP, WCF and ASHP. We contribute to highly understudied area: Finnish SHS decisions. Examining multiple adopted and nonadopted systems gives us a unique perspective and mitigates choice-supportive bias. Our results indicate that SHS adoption has some similar barriers as primary heating system adoption. The SHS choice is complex, uncertainties about suitability exist, and information is scattered and not uniform.

The main findings of this study are summarized below:

- Supplementary heating is widely applied and generally well received in Finland.
- High education decreased the likelihood of being an *ESHS* adopter but increased the likelihood of being an adoption considerer.
- Stating high importance for heating system investment costs decreases the likelihood to adopt supplementary heating.
- Having ground heating as a primary heating mode or living in a district heating network area significantly decreased *ESHS* adoption probability.
- *ESHS* adopters were more likely to consider also other non-adopted supplementary systems than non-adopters.
- Pro-environmental attitudes had a positive impact on *ESHS* adoption.
- Information channels had large relative impacts on supplementary heating adoption decisions. Professional literature positively contributed to *ESHS* adoption.

The main policy and market implications of this study relate to information and targeting. The findings demonstrate that homeowners who were less informed about hybrid heating were also more likely to belong to the group of *ESHS* rejectors. Thus, high quality and easily accessible hybrid heating information provision can ease the future adoption of SHSs. In addition, web-based main heating system calculators and comparison tools were widely known among the studied homeowners, and also had a positive impact on *ESHS* adoption. This indicates that development of heating system comparison tools that also account for supplementary systems could be beneficial for SHS adoption.

The analyses also highlight the importance of careful marketing and policy targeting as demographic, house and area characteristics impact homeowner supplementary heating system decisions. Moreover, environmental benefits can be utilized to promote supplementary heating systems.

Concerning further research, results for newly built detached houses in Finland may not generalize directly for different house types and geographies. Therefore, study of SHS choice determinants for older houses and other countries is warranted. An additional further research topic is to examine how supplementary heating system choices compare with other energy efficiency investments.

CRediT authorship contribution statement

Jouni Räihä: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing - review & editing. **Enni Ruokamo:** Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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